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No. 5

MEASUREMENTS OF THE VELOCITY AND ABSORPTION of ULTRASOUND IN LIQUID GALLIUM

by

R. L. PROFFIT and E. F. CAROME

March 1, 1962

DEPARTMENT OF PHYSICS
JOHN CARROLL UNIVERSITY
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Abstract

Ultrasonic velocity measurements have been made in liquid gallium over the temperature range from 20 to 40°C. The value of the velocity measured at the freezing point, 29.8°C, is 2871.1 $\pm$ 0.3 m/sec and the temperature coefficient of velocity is -0.$\bar{3}$ m/sec/°C. Preliminary absorption measurements also have been made, and the measured value of α/ν^2 is 2.5 $\pm$ 0.3 x 10^{-17} cm^{-1} sec^2 at 30°C.

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Table of Contents

INTRODUCTION

As part of a study in progress, in this laboratory, of various properties of gallium in the liquid and solid states, measurements have been made of the velocity of ultrasound in the vicinity of the freezing point in both the normal liquid and the supercooled regions. From these a value for the temperature coefficient of velocity has been obtained, and more accurate values than previously reported in the literature[1] have been derived for the adiabatic and isothermal compressibilities.

Preliminary measurements also have been made of the absorption of ultrasound in liquid gallium. These were made at frequencies of 205 Mc and below, and yielded only an approximate value for the absorption coefficient.

INSTRUMENTATION FOR VELOCITY MEASUREMENTS

A modified interferometric technique was employed for the velocity measurements. A sketch, drawn roughly to scale, of the main portions of the mechanical system is shown in Fig. 1. The gallium sample was placed within a polyethelene tube attached with epoxy resin to a cylindrical fused quartz delay rod. The acoustic source, an X-cut 5 Mc quartz plate, was mounted at the bottom of this rod. The receiver, an identical X-cut plate, was mounted at the top end of a second fused quartz delay rod and the bottom end of

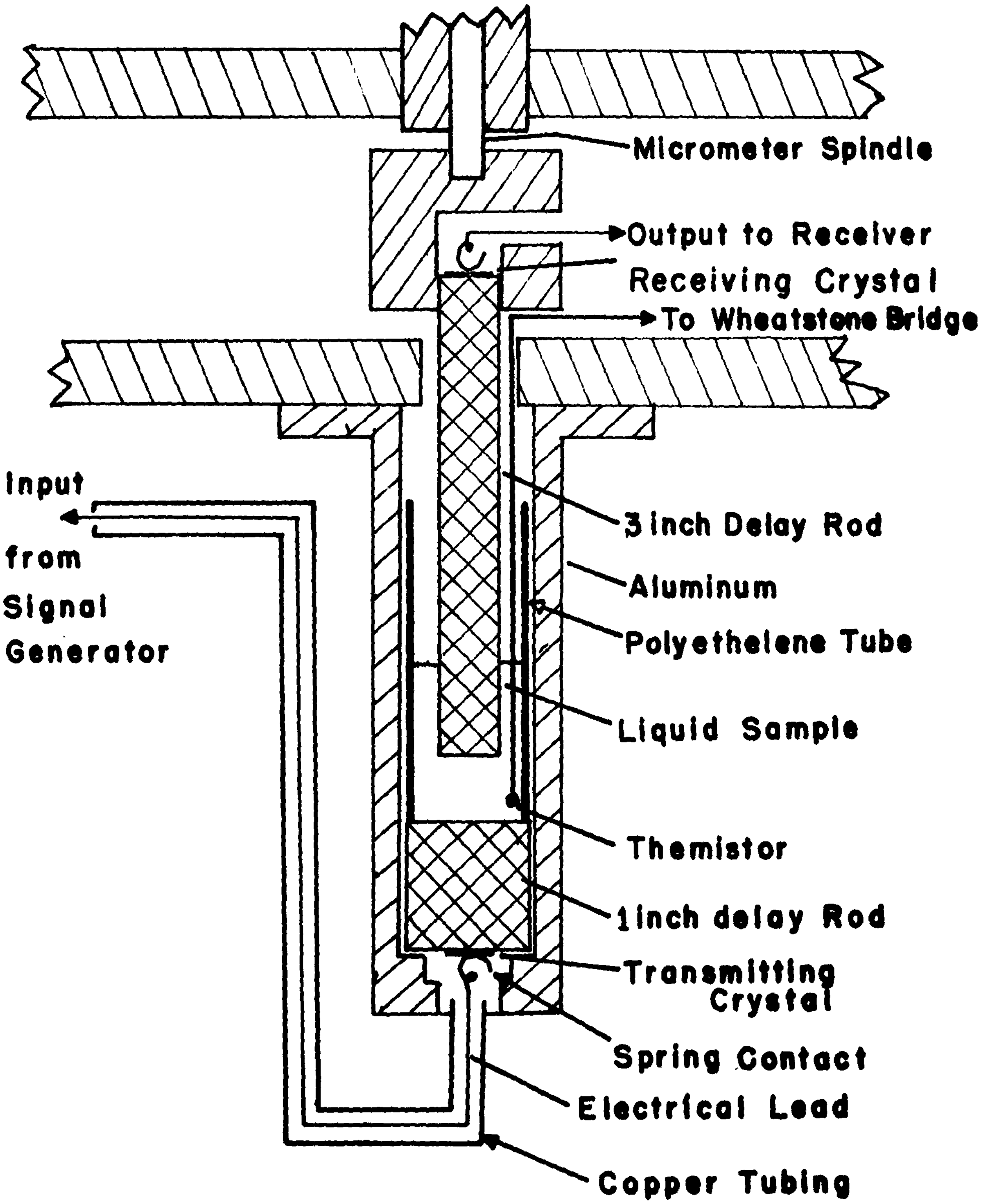

Fig. 1 Details of Interferometer.

this rod was immersed in the gallium sample. A leveling mechanism, not shown in Fig. 1, was provided so that the faces of the two quartz delay rods could be made parallel to one another, as described below. The upper delay rod was attached directly to the non-rotating spindle of a Boekler micrometer,[2] which was used to vary the acoustic path length of the gallium sample. The lower portion of the system containing the sample was submerged in a liquid temperature control bath held to within 0.1°C. A calibrated thermistor, placed within the gallium, was used to determine the temperature of the sample itself.

The required parallelism between the faces of the two delay rods was obtained with the aid of a pulsed oscillator system that was used for the absorption measurements, rather than with the continuous wave velocity apparatus. One or the other of the two quartz crystals shown in Fig. 1 was used as both acoustic source and receiver. Leveling screws separating the support mechanisms of the two delay rods were adjusted to maximize the series of echo pulses produced by multiple reflections within the gallium sample.

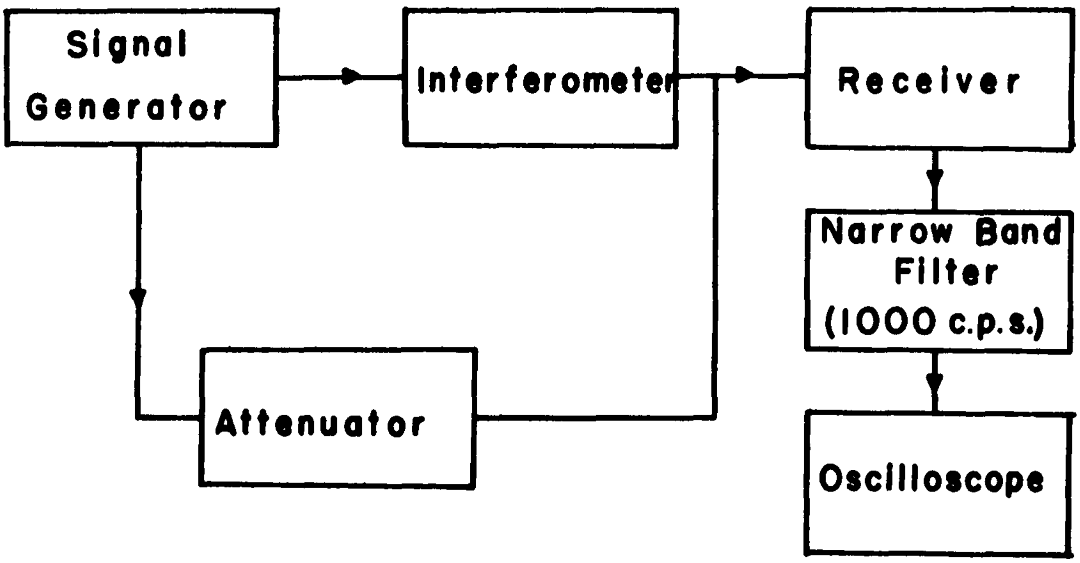

Fig. 2 Block Diagram of Velocity Measurement System.

A block diagram of the entire velocity measurement system is shown in Fig. 2. The output of a standard signal generator, modulated at 1000 cps, was used to excite the acoustic source. The output of the receiving crystal was fed into a communications receiver, where it was mixed with an electrically attenuated signal from the generator.

As the path length in the gallium sample was varied through successive wavelengths, the acoustically delayed signal interfered first constructively and then destructively with the electrically attenuated signal. Thus, the 1000 cps filtered output from the communications receiver, as viewed on an oscilloscope, passed successively through maxima and minima. By setting the amplitude of the electrically attenuated signal so that it was greater than the output of the receiving crystal, even at the shortest acoustic path length, the change in path length between successive maxima corresponded unambigously to an acoustic wavelength. Since the absorption in gallium is very low, the velocity measurements were made at 45 Mc, the ninth harmonic of the crystals, so that the distance between successive maxima was only about 0.0025 in. Therefore, it was possible to locate the position of a given signal extremum quite precisely.

Using the above described system, a measurement of velocity was made by recording first the positions of ten (i.e. 0th to 9th) successive interference maxima. Then the path length was increased through ninety more maxima and the positions of ten more (i.e. 100th to 109th) successive maxima were determined. The distances between each corresponding pair of maxima (i.e. 0th to 100th, 1st and 101st,

etc.) were determined and the average of these ten readings was taken as the path length corresponding to 100 wavelengths. This length and the frequency of the signal generator, which was obtained by comparing its output with that of a frequency meter calibrated against WWV, were then used to compute the velocity.

In order to check the absolute accuracy of this system, velocity measurements were made in distilled water. At 31.6°C, for example, the measured velocity in water was 1512.3 $\pm$ 0.2 m/sec, as compared to the accepted value of 1513.03 $\pm$ .03 m/sec.[3] This and other measurements in water indicate that the system is capable of yielding absolute velocities accurate to about 0.1%, while internally the system has a precision of about 0.03%.

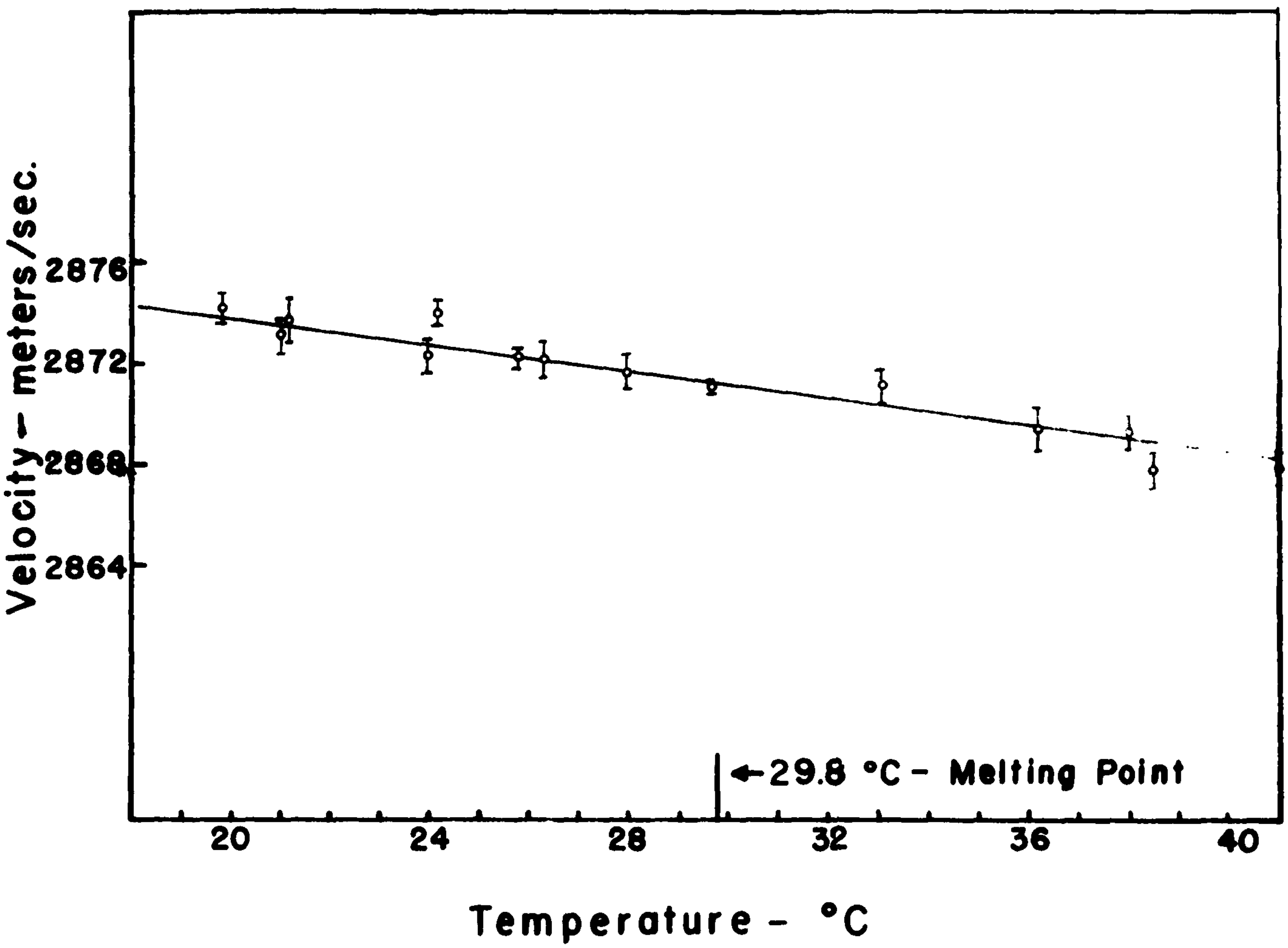

Fig. 3 Velocity versus Temperature for Liquid Gallium.

VELOCITY AND COMPRESSIBILITY DATA

With the above discussed system velocity measurements were made over the temperature range from 20 to 40°C, in a gallium sample of 99.99% purity. The results are listed in Table 1 and plotted in Fig. 3. From the standard deviations of the velocity values it is concluded that the overall accuracy of the measurements is about ± 1 m/sec. From Fig. 3 it may be seen that the variation of velocity with temperature in gallium is about -0.3 m/sec.°C in the vicinity of the melting point, 29.8°C, where the measured velocity is 2871 ± 1 m/sec, as compared to Kleppa's value of 2740 ± 50 m/sec.[1]

Both the adiabatic compressibility K_s, and the isothermal compressibility K_T may be determined in terms of the present velocity measurements. The former is given by the familiar expression

$$K_s = \frac{1}{\rho v^2} \qquad (1)$$

where ρ is the density and v the sound velocity, while the latter may be determined from

$$K_T = \gamma K_s = \left(1 + \frac{TMa^2}{Cp\ K_s}\right) K_s \qquad (2)$$

Here $\gamma = \frac{C_p}{C_v}$ is the ratio of specific heats; T, the absolute temperature; M, the atomic weight; and a the thermal expansion coefficient.[4]

Table 1

Sound velocity versus temperature data for gallium.

Temperature ^{o}C	Velocity (m/sec)	Stand. Dev. $\pm$ m/sec.
19.8	2874.1	0.6
21.0	2873.1	0.6
21.2	2873.7	0.8
24.0	2872.3	0.6
24.2	2873.0	0.5
25.8	2872.3	0.4
26.3	2872.2	0.7
28.0	2871.7	0.7
29.7	2871.1	0.3
33.1	2871.2	0.7
36.2	2869.5	0.8
37.9	2869.3	0.7
38.5	2867.8	0.7
41.0	2867.9	0.7

Using the velocity value at the melting point obtained in the present study the compressibilities and the ratio of specific heats, as given by the expression in the parenthesis in Eq. 2, were computed.

In Table 2, the values obtained are compared with those of Kleppa.[1]

Table 2

Velocity and computed compressibility data for gallium at the melting point, 29.8°C.

Source	v (m/sec)	$K_S \times 10^6$ (bar^{-1})	$\frac{C_p}{C_v}$	$K_T \times 10^6$ (bar^{-1})
Kleppa[1]	2740 ± 50	2.2	1.08	2.4
Present Study	2871 ± 1	1.99	1.09	2.17

The velocity measurements were also examined to determine if the thermal coefficient of velocity in the normal liquid region is different from that in the supercooled region, as suggested by various workers.[5-7] As is evident from Fig. 3, if such a difference exists, it is less than 0.1 m/sec/°C and therefore, could not be detected within the precision of the present setup.

ABSORPTION MEASUREMENTS

During the course of the velocity measurements an attempt was made to determine the sound absorption coefficient α. Standard pulse techniques were used and measurements were attempted over the frequency range from 100 to 205 Mc. Because of the extremely low absorption and the limited path length variation available in the apparatus (approximately 1 cm) it was not possible to obtain a very accurate value for α. The value obtained at 205 Mc was only 8.5 ± 0.8 db/cm, corresponding to $\frac{\alpha}{\nu^2} = 2.5 \times 10^{-17}\,\mathrm{cm}^{-1}\,\mathrm{sec}^2$, at 30°C.

The theoretical Stokes-Kirchoff value for $\frac{\alpha}{\nu^2}$ is given by

$$\frac{\alpha}{\nu^2} = \frac{8\pi^2}{3}\frac{\eta}{\rho V^3} + \frac{2\pi^2(\gamma-1)T}{3} \qquad (3)$$

$$= (0.42 + 1.2)\ \mathrm{cm}^{-1}\ \mathrm{sec}^2$$

where η is the viscosity. As can be seen, the total theoretical loss is very low and these preliminary results indicate that this is also the case experimentally. Further absorption measurements are to be made in the near future at substantailly higher frequencies so that a more accurate value of α should be obtained.

ACKNOWLEDGMENTS

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